SIMILARITY AND PRIORITY OF THE SUBMARINE OFFICER OF THE DECK: ASSESSING KNOWLEDGE STRUCTURES

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ABSTRACT

It is increasingly being recognized that understanding expert knowledge structures associated with critical decision processes may facilitate Naval personnel performance. Toward this end, system developers and training researchers attempt to identify critical components of expert operator assessment and knowledge. Differing domains of practice rely to varying degrees on perceptual and conceptual knowledge. Perceptual knowledge is relied upon for recognizing critical cues in the environment whereas conceptual knowledge is used to interpret the meaning and importance of these cues. We focus on conceptual knowledge given its importance in the submariner environment. Via analyses of submariner knowledge for concepts related to responsibilities for the Officer of the Deck (OOD) watchstander we examined how training may alter knowledge representation and priority of conceptual importance and how overlap in mental models may be due to amount of experience.

INTRODUCTION

It is increasingly being recognized that understanding expert knowledge structures associated with critical decision processes may facilitate Naval personnel performance (e.g., Gray & Kirschenbaum, 2000; Kirschenbaum, 2001; Wyman & Randel, 1998). Toward this end, system developers and training researchers attempt to identify critical components of expert operator assessment and decision processes. From the standpoint of system development, such findings may aid in the identification of important parameters to be included in relevant operational environments (e.g., Schvaneveldt, Beringer, & Lamonica, 2000). From the standpoint of training and performance, targets for learning may be identified (e.g., Fiore, Fowlkes, Martin-Milham, & Oser, 2000). As such, an understanding of the knowledge structures associated with expert decision making is critical to the development of, not only cognitively valid systems, but also efficient training programs.

Differing domains of practice rely to varying degrees on perceptual and conceptual knowledge. *Perceptual* knowledge is relied upon for recognizing critical cues in the environment whereas *conceptual* knowledge is used to interpret the meaning and importance of these cues (e.g., Fiore, Jentsch, Oser, & Cannon-Bowers, 2000). The issue centers on the fact that complex tasks are made up of differing types of knowledge (e.g., declarative, procedural, perceptual) and the acquisition of a particular knowledge type is likely to change as a trainee acquires more experience with a task. For example, Lesgold et al. (1988) noted that task novices initially develop perceptual expertise more rapidly than conceptual expertise, but, with experience, the conceptual expertise gains strength.

Given its importance in the submariner environment, we focus on conceptual knowledge for the following reasons. First, the environment in which a submarine's crew operates differs from the normal environment in significant ways. The submarine environment is a fluid-filled medium, little or no direct visual information is provided, and much of the acoustic information is made available only indirectly and that, too, is in visual form. As a consequence, mental representations of the submariner's world can be greatly impacted. Second, through technological advances, increasing amounts of information are available to the submarine watchstander, especially the Officer of the Deck (OOD) (Shobe, 2001). The OOD controls the boat and executes his mission by making sense of information presented by external sensors and internal processing. The OOD uses this information to build his mental model and, in this study, we examined knowledge representation within experienced submariner officers in order to determine how such knowledge may change with experience.

We next describe our analyses of submariner knowledge for concepts related to responsibilities for the OOD task. We examined how training may alter knowledge representation, and how overlap in mental models may be due to amount of experience. Similar research has assessed the nature and sharedness of mental models for submariners. For example, Smith-Jentsch et al. (2001) looked at how experience influenced mental models of teamwork and found greater agreement based upon either rank or years in service. Additionally, when compared to an expert model, those with a higher rank showed greater agreement. We expand upon that research to examine how mental models associated with the OOD task may show similar patterns and further investigate how information priority may change due to experience. Priority rankings data for task related concepts may elucidate differences in conceptual knowledge across groups varying in experience. For example, in a study looking at phases of flight, Schvaneveldt, Beringer, and Lamonica (2000) found that this technique was able to highlight differences in

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perceptions of importance dependent upon the level of expertise of the pilots.

Based upon shared mental model theory (e.g., Cannon-Bowers, Converse, & Salas, 1993; Fiore, Salas, & Cannon-Bowers, 2001), we hypothesized that, first, the experienced participants would show greater similarity within their groups and to an expert model. Second, following training, novice participants would (a) show greater agreement in mental models for the critical concepts, and (b) show greater agreement with expert participants (i.e., a composite model based upon the input of a group of expert participants). Additionally, rankings of importance for these critical concepts were expected to show how novice and less experienced personnel may misunderstand priorities associated with decision-making criteria when compared to experts.

METHOD

Participants

Experienced participants ($N = 40$) were qualified Officers of the Deck (OOD) in Submarine Officer Advanced Course (SOAC). Novice participants ($N = 50$) were students in their first week of Submarine Officer Basic Course (SOBCpre) with no OOD experience. These same participants were tested again at the end of the 12 week course (SOBCpst). The SOBC group is not OOD qualified, but after completion of the course they have had all the relevant lectures and trainer experience. Years in Service for participants in the SOBC group ($M = 5.12$ years) was significantly lower than that of participants in the SOAC group ($M = 10.58$ years), $F\ (1, 89) = 34.76$, $p < .001$. Years in Present Rank for participants in the SOBC group ($M = 1.6$ years) was significantly lower than that of participants in the SOAC group ($M = 3.3$ years), $F\ (1, 88) = 62.66$, $p < .001$. Years Sea Duty for participants in the SOBC group ($M = 1.1$ years) was significantly lower than that of participants in the SOAC group ($M = 3.8$ years), $F\ (1, 89) = 35.92$, $p < .001$. Data from a small group of experts ($N = 4$) was also collected in order to develop an expert composite model for comparison to the more and less experienced participants. The expert participants were all Lieutenant Commanders and overall, had an average length of 8.9 years in that rank. The mean number of years in service was 20.4, with an average of 6.5 years submarine sea duty. All of the expert participants had served as department heads on submarines and were currently filling a Post-Department Head shore tour billet.

Materials

Critical categories of information available to the submarine OOD were printed separately on 20 index cards. Each of the 20 cards contained a piece of information available at CONN for navigation and ship safety. Tactical and weapons information was not provided.

Procedure

Participants performed both a card sorting and ranking task to indicate similarity and relative importance among categories of information available on submarines in different operational environments. Participants were instructed to sort the cards into piles according to similarity and were not constrained by the number of piles they could create. Following the card sorting task, participants ranked the cards according to relative importance. They were instructed to create a single pile of cards ordered from the most important piece of submarine information to the least important.

Design

This experiment manipulated experience level (experienced vs. novice) as a between participant factor. For the concept rankings measure, operational scenario was manipulated via factorial combination of presence/absence of enemy and shallow/deep water.

RESULTS

For the card sort data, in order to assess the relation among concept pairs, each possible concept pair ($N = 210$) was coded with a 0 if the participant did not group them in the same category, or a 1 if they were grouped in the same category. For the concept rankings data, mean concept importance was calculated for each concept across groups and scenarios.

Mental Model Similarity for Card Sort Data

Overall Correlations. This data determines the degree to which participants may differ in their mental models of critical OOD concepts. Using the concept pair coding scheme described above we computed correlations with all possible participant pairings. These cross-correlations were run across and within the three participant groups (SOAC, SOBCpre, SOBCpst). The data based upon this matrix thus had six conceptual groups: (1) SOAC correlated with SOAC; (2) SOAC correlated with SOBCpst; (3) SOAC correlated with SOBCpre; (4) SOBCpre correlated with SOBCpst; (5) SOBCpst correlated with SOBCpst; and, (6) SOBCpre correlated with SOBCpre. This data was subjected to a Univariate ANOVA and resulted in a significant main effect for group type, $F\ (5, 8250) = 20.95$, $p < .001$. For ease of explication we present this data as mean *within* group correlations and mean *across* group correlations. Specifically, the *within* group correlations corresponded to "SOAC correlated with SOAC", "SOBCpst correlated with SOBCpst", and "SOBCpre correlated with SOBCpre". The *across* group correlations corresponded to "SOAC correlated with SOBCpst", "SOAC correlated with SOBCpre", and "SOBCpre correlated with SOBCpst" (refer to Figure 1). Unless otherwise specified, the reported post-hoc analyses are all significant at the $p < .05$ level.

When considering the *within* group comparisons, post-hoc analyses showed that the degree of mental model similarity was significantly greater for the more experienced (SOAC) participants ($M = .39$). The degree of mental model similarity was significantly lower for the least experienced (SOBCpre) participants ($M = .33$), with mental model similarity for SOBCpst in between, and significantly different from, the other groups ($M = .35$). When considering the *across* group

comparisons, post-hoc analyses showed that the degree of across group mental model similarity was greatest for SOAC and SOBCpst (M = .36). Correlations between SOBCpre and SOBCpst (M = .33) and between SOAC and SOBCpre (M = .33) were both significantly lower than the correlation between SOAC and SOBCpst.

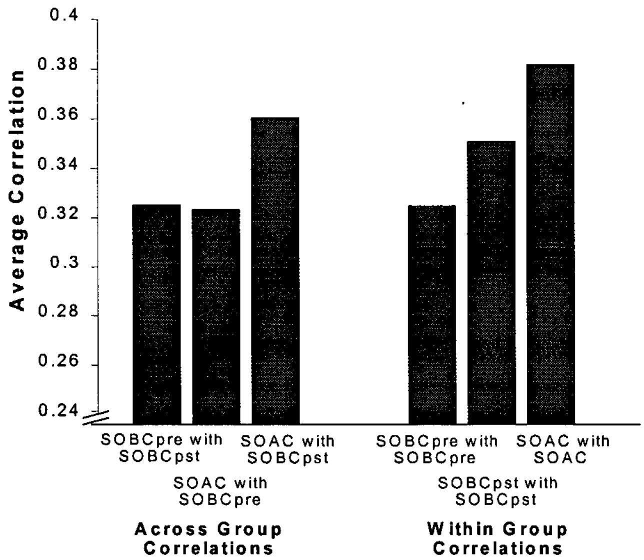

Figure 1. Mean correlations across all possible participant pairings resulting from card sort data.

Similarity to Expert Composite Model. We additionally examined the degree to which these participant groups generated mental models similar to a composite expert model. We were interested in assessing whether training and/or experience influenced structural similarity to an expert model and we hypothesized that the differing groups would show differing levels of similarity to the expert model. For this analysis, we computed mean correlations with the expert composite model for each participant group. An ANOVA revealed a main effect of group F (2, 126) = 19.76, $p < .001$. Post-hoc analyses showed that the SOAC participants (M = .43) were significantly higher in agreement to the expert model than were the SOBCpst participants (M = .35), who were, in turn, significantly higher than the SOBCpre participants (M = .28).

Concept Rankings of Importance

We next discuss a portion of the results pertaining to our analyses of the degree to which trainees view *concept importance* differently. Multi-dimensional scaling on the card sort data for the composite expert group was used to identify clusters (reported in Shobe, 2002). These clusters served as an organizing framework with which to analyze and interpret the differences in importance ratings and more specifically target problematic concepts within the overall knowledge structure. Due to page limitations, we only report the overall effects for the rankings data and the comparisons to the expert group and only for a portion of the clusters. For illustrative purposes, these concepts are graphed according to a difference score calculated using the mean expert score. A negative score means participants within a given group, on average, viewed this concept as less important than the expert group.

Own Ship Parameters and Contact Management. Table 1 shows the concepts for the "Own Ship Parameters and Contact Management" cluster. The mean concept importance ratings for the four groups (SOAC, SOBCpre, SOBCpst, Experts) was subjected to a Multivariate ANOVA. Group type was the independent factor and the seven concepts identified in Table 1 were the dependent variables. There was a significant multivariate main effect for group type, F (21, 1560) = 6.51, $p < .001$. For ease of explication, Table 2 presents the between subjects effects for this analysis. Similarly, Figure 2 illustrates the pattern of differences for the effect of group type on mean concept rankings for the Own Ship Parameters and Contact Management cluster. Significant differences between the Expert group and the participant groups are noted in the footnotes for Table 2.

Table 1
Concept Names and Explanations for the Own Ship Parameters and Contact Management Cluster

Cluster One: Own Ship Parameters and Contact Management

	Concept	Description
1	ESM contact data	Bearing and classification of radar and communications systems data provided by the Electronic Support Measures system
2	Own ship data	Own ship's course, speed, depth, etc.
8	Visual contact data (from photonics mast)	Visual information on surface contacts including night vision, infrared, video, laser ranging etc.
14	Geosit/ops summary	Computer generated geographical picture of contacts and own ship, in either true or relative bearing orientation, with classification information where possible
15	Trial own ship	CPA solutions, trial maneuvers, etc., i.e., data which aid in assessment of the present and future tactical situation
16	Non-target fire control solution	Rapid passive localization by wide aperture array (WAA), KAST ranging, multipath ranging, D/E ranging, hyperbolic ranging; Bearing, range, course, speed, depth if submerged contact, for secondary contacts
19	Target fire control solution	Rapid passive localization by wide aperture array (WAA), KAST ranging, multipath ranging, D/E ranging, hyperbolic ranging; Bearing, range, course, speed, depth if submerged contact, for target of interest

Table 2
Results from Multivariate Analysis for Own Ship Parameters and Contact Management Cluster

Source	DV	Type III SS	df	Mean Square	F	Sig.
Participant Group	C01 [a]	803.098	3	267.699	10.359	.000
	C02 [e]	61.430	3	20.477	1.274	.283
	C08 [a]	1813.450	3	604.483	18.289	.000
	C14 [c]	466.602	3	155.534	9.513	.000
	C15 [e]	302.838	3	100.946	5.417	.001
	C16 [b]	410.182	3	136.727	7.004	.000
	C19 [d]	368.573	3	122.858	5.398	.001
Error	C01	13540.902	524	25.841		
	C08	17319.459	524	33.052		
	C14	8566.914	524	16.349		
	C15	9764.677	524	18.635		
	C16	10228.477	524	19.520		
	C19	11925.379	524	22.758		

Notes:
[a] SOBCpre, SOBCpst, and SOAC significantly different from Expert Group
[b] SOBCpre and SOBCpst significantly different from Expert Group
[c] SOBCpst significantly different from Expert Group
[d] SOAC significantly different from Expert Group
[e] None significantly different from Expert Group

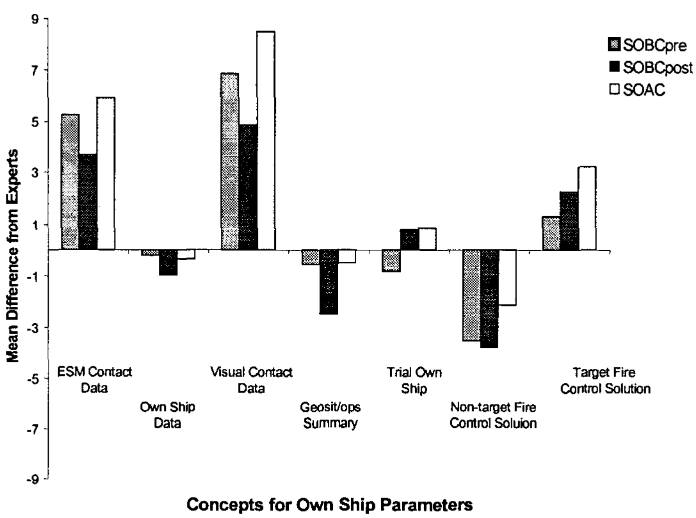

Figure 2. Difference scores for Own Ship Parameters and Contact Management cluster.

Sonar Tactical Displays. Table 3 lists and defines the concepts making up the "Sonar Tactical Displays" cluster. The mean concept importance ratings for the four groups (SOAC, SOBCpre, SOBCpst, Experts) was subjected to a Multivariate ANOVA. Group type was the independent factor and the four concepts identified in Table 3 were the dependent variables. There was a significant multivariate main effect for group type, F (12, 1569) = 12.06, $p < .001$. For ease of explication, Table 4 presents the between subjects effects for this analysis. Similarly, Figure 3 illustrates the pattern of differences for the effect of group type on mean concept rankings for the Sonar Tactical Displays cluster. Significant differences between the Expert group and the participant groups are noted in the footnotes for Table 4.

Table 3
Concept Names and Explanations for the Sonar Tactical Displays Cluster

Cluster Four: Sonar Tactical Displays		
	Concept	**Description**
3	PMFL data	Data on fault location and performance monitoring of various sonar components, i.e., data required to maintain electrical information systems
12	Sonar tracker/cursor audio	Auditory presentation of minimally processed sonar signals as picked up by the various arrays
17	Sonar detection displays	Visual displays of sonar detections as presented to sonar operators
20	Sonar class displays	Sonar signal interpretation aids such as signature assemblies, lofargrams, etc. i.e., data used to aid in the classification of signals

Table 4
Results from Multivariate Analysis for Sonar Tactical Displays Cluster

Source	DV	Type III SS	df	Mean Square	F	Sig.
Participant Group	C03 [a]	451.424	3	150.475	12.091	.000
	C12 [a]	97.034	3	32.345	1.634	.180
	C17 [b]	2464.951	3	821.650	44.870	.000
	C20 [c]	421.197	3	140.399	6.511	.000
Error	C03	6521.256	524	12.445		
	C12	10370.959	524	19.792		
	C17	9595.292	524	18.312		
	C20	11298.864	524	21.563		

Notes:
[a] None significantly different from Expert Group
[b] SOBCpre and SOBCpst significantly different from Expert Group
[c] SOBCpre, SOBCpst, and SOAC significantly different from Expert Group

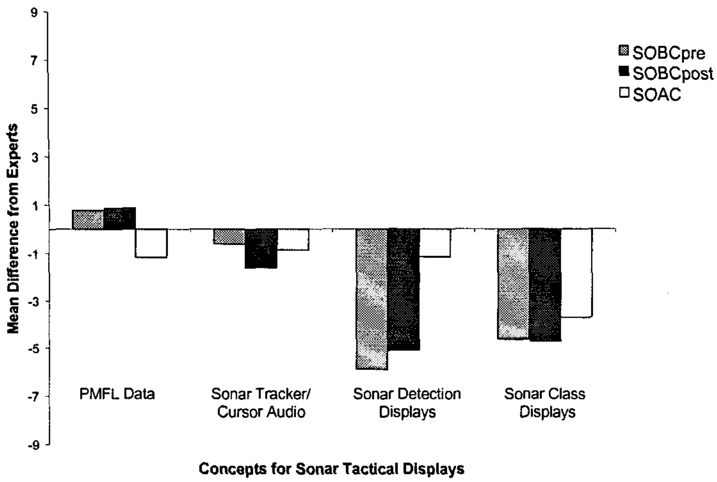

Figure 3. Difference scores for Sonar Tactical Displays Cluster.

DISCUSSION

In support of shared mental model theory and consistent with other studies of knowledge organization and the mental models of submariners (e.g., Smith-Jentsch et al., 2001), this investigation found that more experienced personnel viewed conceptual linkages more similarly and showed higher agreement with an expert model (Fiore, Fowlkes, Martin-Milham, & Oser,, 2000). Conversely, the least experienced personnel saw conceptual linkages less similarly, but, following training, these participants were found to view the conceptual linkages more similarly to the experienced personnel. From the standpoint of understanding the importance of particular concepts, significant differences between experienced and novice personnel were identified prior to, and following, training. This data highlight how participants vary in their understanding of the importance of these concepts.

Linking the conceptual groupings with the priorities data can better illuminate knowledge organization and the differing ways that knowledge may be tapped in operational environments (cf. Schvaneveldt et al., 2001). From the standpoint of training, this data suggest that the conceptual grouping garnered from the expert group may aid in conveying important clusters of information as well as how priorities vary within these clusters. This data is theoretically important because, from the mental model standpoint, it distinguishes more and less experienced personnel on the basis of *critical misconceptions* in item importance. This data is practically important because these misconceptions can be considered as targets for training. For example, this allows one to identify over- and under-statement of importance for trainees at different levels. This, in turn, suggests what concepts need augmentation in the training (i.e., where misconceptions in concept importance lie before and after training) and may help with redesign of systems based upon the importance of data.

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REFERENCES

Cannon-Bowers, J. A., Salas, E., & Converse, S. A. (1993). Shared mental models in expert team decision making. In N. J. Castellan, Jr. (Ed.), *Current issues in individual and group decision making* (pp. 221-246). Hillsdale, NJ: Lawrence Erlbaum Associates.

Fiore, S. M., Fowlkes, J., Martin-Milham, L., & Oser, R. L. (2000). Convergence or divergence of expert models: On the utility of knowledge structure assessment in training research. *Proceedings of the 44th Annual Meeting of the Human Factors and Ergonomic Society, 2, 427-430,* Santa Monica, CA: Human Factors and Ergonomics Society.

Fiore, S. M., Jentsch, F., Oser, R., & Cannon-Bowers, J. A. (2000). Perceptual and conceptual processing in expert/novice cue pattern recognition. *International Journal of Cognitive Technology, 5, 17-26.*

Fiore, S. M., Salas, E., & Cannon-Bowers, J. A. (2001). Group dynamics and shared mental model development. In M. London (Ed.), *How people evaluate others in organizations: Person perception and interpersonal judgment in Industrial/Organizational psychology* (pp. 309 – 336). Mahwah, NJ: Lawrence Erlbaum Associates.

Gray, W. D., & Kirschenbaum, S. S. (2000). Analyzing a novel expertise: An unmarked road. In J. M. C. Schraagen, S. F. Chipman, & V. L. Shalin (Eds.), *Cognitive task analysis* (pp. 275-290). Mahwah, NJ: Erlbaum.

Kirschenbaum, S. S. (2001). Analyzing submarine decision making: A question of levels. In E. Salas and G. Klein (Eds.), *Linking expertise and naturalistic decision making* (pp. 189-207). Mahwah, NJ: Lawrence Erlbaum Associates.

Lesgold, A.M., Rubinson, H., Feltovich, P., Glaser, R., Klopfer, D. & Wang, Y. (1988). Expertise in a complex skill: Diagnosing x-ray pictures. In M.T.H. Chi, R. Glaser & M.J. Farr (Eds.), *The nature of expertise* (pp. 311-342). Hillsdale, NJ: Erlbaum.

Schvaneveldt, R. W. (1990). *Pathfinder associative networks: Studies in knowledge organization.* Norwood, NJ: Ablex.

Schvaneveldt, R. W., Beringer, D. B., & Lamonica, J. A. (2001). Priority and organization of information accessed by pilots in various phases of flight. *International Journal of Aviation Psychology, 11(3)*, 253-280.

Shobe, K. K. (2001). The role of the human operator in the submarine. *The Submarine Review, October,* 58-64.

Shobe, K. K. (2002). Information organization and modeling of the submarine officer of the deck and sonar operator. Paper presented at Office of Naval Research Workshop on Attention, Perception and Data Visualization, May 22 – 24, George Mason University.

Smith-Jentsch, K. A., Campbell, G. E., Milanovich, D. M., & Reynolds, A. M. (2001). Measuring teamwork mental models to support training needs assessment, development, and evaluation: Two empirical studies. *Journal of Organizational Behavior, 22(SpecIssue)*, 179-194.

Wyman, B. G., & Randel, J. M. (1998). The relation of knowledge organization to performance of a complex cognitive task. *Applied Cognitive Psychology, 12*, 251-264.